

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

SPECIFICATION

TITLE OF THE INVENTION

CLAY/ORGANIC CHEMICAL COMPOSITIONS USEFUL AS ADDITIVES TO
POLYMER, PLASTIC AND RESIN MATRICES TO PRODUCE
NANOCOMPOSITES
AND NANOCOMPOSITES CONTAINING SUCH COMPOSITIONS

INVENTORS

MARK ROSS
JACOB KAIZERMAN

PATENT COUNSEL:
MICHAEL J. CRONIN
REGISTRATION NO. 35,848
RHEOX, INC.
WYCKOFFS MILL ROAD
HIGHTSTOWN, NJ 08520
TEL: (609)443-2590
FAX: (609)443-2306

CLAY/ORGANIC CHEMICAL COMPOSITIONS USEFUL AS ADDITIVES TO POLYMER, PLASTIC AND RESIN MATRICES TO PRODUCE NANOCOMPOSITES AND NANOCOMPOSITES CONTAINING SUCH COMPOSITIONS

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BACKGROUND OF THE INVENTION

Field of the Invention:

The present invention is directed to improved clay/organic chemical compositions that are made from clay and a specified mixture of organic materials. The compositions can be added to a wide variety of polymer, plastic and resin matrices to form inventive nanocomposite materials of enhanced structural strength. They can also be used as rheological additives.

Background of the Invention

Organically modified clays, also called organoclays, have been used for many years as rheological additives for solvent based systems. They are usually produced by making a water dispersion of a phyllosilicate clay, usually a smectite clay, and adding to it a quaternary ammonium salt of a long chain fatty acid to produce an organically modified clay by cation exchange reaction and adsorption. The reaction may cause the organoclay to coagulate from the water dispersion which allows for its isolation by filtration and washing. Similarly, organoclays can be made without water by extrusion mixing, with heat and shear, smectite clay and the quaternary ammonium compound or compounds with no water or other solvent being present. This process usually produces an organoclay of lower quality however, since, among other reasons, the final product still has salt reaction byproducts that cannot be washed or readily isolated from the organoclay and for other reasons.

Polymers, resins and plastics containing clay additives have recently become widely used as replacements for heavier steel and other metal products, especially in the field of automotive manufacturing. They have also found use in a growing number of other areas including as bridge components and as replacements for heavier steel parts in ship construction. Using extrusion and injection molding, a nylon matrix, for example, has been successfully reinforced with smectite-type clays (and organoclays based on the smectite clays, bentonite and hectorite) dispersed therein to form molecular composites of nylon and finely dispersed silicate clay platelet layers. Such products, often called nanocomposites, have enhanced structural, tensile, impact and flexural strength.

The behavior of the resultant plastic/clay product (or nanocomposite) is qualitatively different from that exhibited by the plastic, polymer or resin alone and has been attributed by some workers in the field to the confinement of the matrix chains between the clay's millions of microscopic layers. It has long been known that bentonite and hectorite are clays which are composed of flat silicate platelets of a thickness no more than about one nanometer.

The nanocomposite products created to date have important commercial applications not only in the synthesis and properties of organic/inorganic nano-structures as discussed above but also in diverse areas such as where ultrathin polymer films confined between adsorbed surfaces are involved. These uses include polymer composites for polymer adhesives and films including polyethylene.

The clays used are typically smectite clays which are layered phyllosilicates. Smectite clays possess some structural characteristics similar to the more well-known minerals talc and mica. Their crystal structures consist of two-dimensional layers formed by fusing two silica tetrahedral sheets to an edge-shared dioctahedral or trioctahedral sheet of either alumina (for example bentonite) or magnesia (for example hectorite) - each of the different smectite clays having somewhat different

structures. Stacking of these layers in nature in depths of hundreds or more caused by ionic and weak Van der Waals forces leads to voids or chambers between the separate layers. These chambers are occupied by cations which balance the charge deficiency that is generated by isomorphous substitution (often called disharmonies) within the platelet lattices.

5 Nanocomposites are most often prepared today using organically modified silicates or organoclays produced by a cation exchange reaction between the silicate and an alkylammonium salt (usually quaternary ammonium compounds). The alkyl cations exchanged onto the natural clay platelets render the hydrophilic clay organophilic and this transformation makes the clay more easily dispersible into the polymer or plastic. Although excellent sorbents for some organics, natural bentonite and hectorite are themselves very hydrophilic.

Description of the Prior Art:

10 The earliest scientific work using organoclays in the preparation of nanocomposites is reflected in U.S. Patent 2,531,396, issued to a predecessor of Rheox, Inc., the assignee of this invention. This patent filed in 1947 teaches the use of organically modified bentonites to provide structural reinforcement to elastomers, such as rubber, polychloroprene and polyvinyl compounds. 15 Over a generation later, additional patents begin to appear. A number of patents obtained by Toyota starting in 1984: U.S. Patent Nos. 4,472,538; 4,739,007; 4,810,734; 4,889,885; and 5,091,462 use organoclay additives for plastics and describe plastic structures commercially used, for example, to replace steel components in automobiles.

20 While not related to nanocomposites, Rheox, Inc. has issued patents describing organoclay compositions useful as rheological additives which comprise the reaction product of smectite clay, quaternary ammonium compounds and organic anions wherein a quaternary-organic anion complex

is intercalated with the smectite clay - see for example U.S. Patent No. 4,412,018 - organic anions are described to include a large variety of organic compounds, including carboxylic acids, capable of reacting with the quaternary used.

Manufacture to date of nanocomposite materials has often involved mixing an organoclay with a polymer powder, pressing the mixture into a pellet, and heating at the appropriate temperature. For example, polystyrene has been intercalated by mixing polystyrene with an alkylammonium montmorillonite and heating in vacuum. Temperature of heating is chosen to be above the bulk glass transition temperature of polystyrene ensuring polymer melt.

Representative U.S. Patent No. 4,810,734 to Toyota describes a different process for producing a composite material which comprises a step of contacting a layered smectite clay mineral having a cation exchange capacity of up to 200 milliequivalents per 100 g with a swelling agent in the presence of a dispersion medium, thereby forming a complex which has the property of being swollen by a molten monomer of a polymer, and a polymerization step of polymerizing said monomer in said mixture. The "swelling agent" used is one which has both an onium ion and a functional group capable of reacting with a polymer. Toyota U.S. Patent No. 4,889,885 describes a composite material, which comprises (a) at least one resin selected from the group consisting of a vinyl-based polymeric compound, a thermosetting resin and a rubber, and (b) a layered bentonite uniformly dispersed in the resin, the layered silicate having a layer thickness of about 7 to 12 Å and an interlayer distance of at least about 30 Å, where at least one resin is connected to a layered silicate through an intermediate.

There are a number of ECC America patents issued starting around 1987 where gaseous NH_3 is used to provide modification of the smectite clay surfaces prior to making a nanocomposite - See

U.S. Patent No. 4,690,868 and 4,798,766.

Two other major companies appear to be working in the field; Amcol International Corporation and AlliedSignal. Both have issued recent patents in the area of this invention. See for example AlliedSignal's U.S. Patent Nos. 5,514,734 and 5,385,776 - these patents are in general directed toward a nylon 6 matrix and clays using non-standard organic modifications. See also in this regard Vaia et al., the article entitled Synthesis and Properties of Two-Dimensional Nano Structures By Direct Intercalation of Polymer Melts in Layered Silicates, Chemical Materials 1993, 5, pages 1694-1696.

Amcol International Corporation (Amcol) has been issued as least three recent patents, U.S. Patent Nos. 5,552,469, 5,578,672 and 5,698,627 which teach the exclusion from their clay-based nanocomposites of "onium ion" products (which would include most known commercial organoclays made with traditional quaternary ammonium compounds). See also Amcol U.S. Patent No. 5,721,306.

Several patents of the Cornell Research Foundation have issued - U.S. Patent No. 5,032,546, 5,032,547 and 5,554,670. One or more of these patents describe the use of organoclays made by the Southern Clay Corporation, Texas.

General Electric Company U.S. Patent No. 5,530,052 describes silicate materials, including montmorillonite clays, modified with at least one heteroaromatic cation and used as additives to specified polymers to make nanocomposites.

Other prior art shows making polymer-clay intercalates directly by reaction of the monomers in the presence of clays. See Interfacial Effects On The Reinforcement Properties Of Polymer Organoclay Nanocomposites, H Shi, T Lan, TH Pinnavaia, Chemistry of Materials, 1996, pages 88

et seq.

Many of the products described in the prior art references described above have the problem that they are either easy to process and isolate, but are difficult to disperse in a matrix, or they have improved dispersing characteristics but are inconvenient to isolate when manufactured. Traditional organoclays manufactured from quaternary salts and smectite clays are easy to isolate and wash because the reaction of onium salts with ion-exchangeable clays form hydrophobic materials in water that can be conveniently filtered. These materials, however, do not have good compatibility with certain plastic materials.

Water soluble polymer-clay intercalates as described in US 5,552,469, for example, can have good compatibility with polymer, resin and plastic materials, but to isolate the additive, one must boil off residual water in an energy intensive fashion. This process also has the potential to leave behind unintercalated polymer along with the clay-polymer intercalate for which there is no simple way of removal. Making a clay-monomer composition with subsequent polymerization can give a well dispersed system in the polymer. Unfortunately, this technique requires that an expensive polymerization train be dedicated to the process and plant contamination with clay can become an issue.

What has escaped scientists is an inexpensive way to make an organic/clay composition that can easily and economically be isolated in high purity and also can be simply processed into a polymer, plastic or resin matrix to form a nanocomposite.

OBJECT AND SUMMARY OF THE INVENTION

Object of the Invention

It is an object of the invention to provide a clay/organic chemical composition (which we also call a hybrid organoclay) that can be readily dispersed in plastic and polymer materials to make nanocomposites of improved structural strength.

It is a specific object of the invention to provide such a clay/organic chemical composition that can be readily made and provide use as a rheological additive.

It is a still further object of the invention to provide an inexpensive process to make the clay/organic chemical composition in a manner that can be isolated readily.

Summary of the Invention:

This invention is of a clay/organic chemical composition that consists of an organic chemical/smectite clay intercalate that has been ion-exchanged and reacted with one or more quaternary ammonium compounds. This composition is designated as a hybrid organoclay. Since such a hybrid organoclay is hydrophobic, it can be washed with water after manufacture to remove reaction salts and excess water soluble or water dispersible organic material to give a clean product via inexpensive means such as filtration. This allows a better dispersing composition to be prepared without the difficulties of isolation presented by prior art, which uses energy intensive means to remove the bulk of the water from the final product and cannot be easily washed.

In one aspect, the present invention provides a clay/organic chemical composition that comprises: (a) one or more smectite clays, (b) one or more quaternary ammonium compounds which react via an ion exchange mechanism with the clay, and (c) one or more defined non-anionic organic materials that are intercalated with the smectite clay.

Further advantages and features of the invention, as well as the scope, nature and utilization of the invention, will become apparent to those of ordinary skill in the art from the description of the preferred embodiment of the invention set forth below.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

5 The clay/organic chemical compositions of this invention, which are also referred to as hybrid organoclays, may be made using a variety of materials and by a variety of methods disclosed hereafter, or which will appear obvious when the disclosure of this patent occurs. Applicants do not intend to limit the materials or methods of manufacture of such additives by the following descriptions.

10 One important aspect of the invention is a clay/organic chemical composition, i.e., a hybrid organoclay, comprising an ion-exchanged reaction product obtained by the intercalation and reaction of:

- 15 a) one or more smectite clays;
- b) one or more quaternary ammonium compounds; and
- c) one or more non-anionic organic materials.

The latter two materials can be reacted and intercalated together, or in any order, with the smectite clay to produce an inventive composition which can be isolated, washed and filtered at low cost.

20 Clays useful for element a) are smectite clays. Such clays are swellable layered clays which contain individual platelets which increase their interlayer spacing upon application of either element b) or c). Useful swellable layered materials include phyllosilicates such as smectite clay minerals, e.g., montmorillonite, particularly sodium montmorillonite; bentonite; hectorite; saponite; stevensite;

beidellite; and the like.

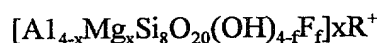
As used herein the term "interlayer spacing" refers to the distance between the internal faces of adjacent dry smectite clay platelet layers as they are assembled in the layered clay before any delamination takes place. The interlayer spacing is measured when the clay is dry; i.e., contains less than 3-6% by weight of water based on the dry weight of the material.

The clays which may be used in the present invention are preferably smectite-type clays having a cationic exchange capacity of at least 50 milliequivalents per 100 grams of clay, 100% active clay basis, as determined by the well-known ammonium acetate or methylene blue methods. Preferred smectite materials are bentonite and hectorite clays particularly of the 2:1 type having a negative charge on the layers ranging from about 0.15 to about 0.9 charges per formula unit and a commensurate number of exchangeable metal cations in the interlayer spaces.

Smectite-type clays are well known in the art and are commercially available from a variety of sources. Prior to use in the invention, the clays may preferably be converted to the sodium form if they are not already in this form. This may be conveniently carried out by preparing an aqueous clay slurry and passing the slurry through a bed of cation exchange resin in the sodium form. Alternatively, the clay can be mixed with water and a soluble sodium compound, such as sodium carbonate, sodium hydroxide, etc., and the mixture sheared, such as with a pugmill or extruder.

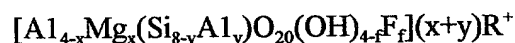
Representative smectite clays useful in accordance with the present invention are the following:

Montmorillonite



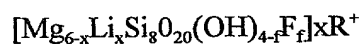
where $0.55 \leq x \leq 1.10$, $f \leq 4$ and R is selected from the group consisting of Na, Li, NH_4 , and mixtures thereof;

5 Bentonite



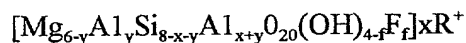
where $0 < x < 1.10$, $0 < y < 1.10$, $0.55 \leq (x + y) \leq 1.10$, $f \leq 4$ and R is selected from the group consisting of Na, Li, NH_4 , and mixtures thereof;

Hectorite



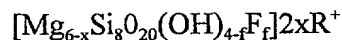
where $0.57 \leq x \leq 1.15$, $f \leq 4$ and R is selected from the group consisting of Na, Li, NH_4 , and mixtures thereof;

Saponite



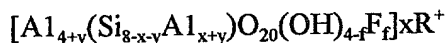
where $0.58 \leq x \leq 1.18$, $0 \leq y \leq 0.66$, $f \leq 4$ and R is selected from the group consisting of Na, Li, NH_4 , and mixtures thereof; and

Stevensite



where $0.28 \leq x \leq 0.57$, $f = 4$ and R is selected from the group consisting of Na, Li, NH_4 , mixtures thereof.

Beidellite

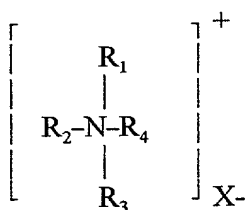


where $0.55 \leq x \leq 1.10$, $0 \leq y \leq 0.44$, $f \leq 4$ and R is selected from the group consisting of Na, Li, NH_4 , and mixtures thereof;

5 The preferred clays used in the present invention are bentonite and hectorite. Bentonite and its properties are described at length in the chapter entitled "Bentonite," in Carr, D., ed. 1994, Industrial Minerals and Rocks, 6th Edition (published by the Society For Mining, Metallurgy and Exploration, Colorado).

10 It will be understood that both sheared and non-sheared forms of the above-listed smectite clays may be employed. In addition, the smectite clay employed can be either crude (containing gangue or non-clay material) or beneficiated (gangue removed). The ability to use crude clay in the smectite-type clay of this invention represents a substantial cost savings, since the clay beneficiation process and conversion to the sodium form do not have to be carried out.

15 Compound(s) b) of the invention is a quaternary ammonium compound(s) which include those having the formula:



20 wherein R_1 comprises a group selected from (i) linear or branched aliphatic, aralkyl, or aromatic hydrocarbon groups having from 8 to 30 carbon atoms or (ii) alkyl or alkyl-ester groups having 8 to 30 carbon atoms; R_2 , R_3 and R_4 are independently selected from the group consisting of (a) linear or

branched aliphatic, aralkyl and aromatic hydrocarbon, fluorocarbon or other halocarbon groups having from 1 to about 30 carbon atoms; (b) alkoxyated groups containing from 1 to about 80 moles of alkylene oxide; (c) amide groups, (d) oxazolidine groups, (e) allyl, vinyl, or other alkenyl or alkynyl groups possessing reactive unsaturation and (f) hydrogen; and X⁻ comprises an anion selected from the group consisting of chloride, methyl sulfate, acetate, iodide and bromide, preferably chloride. For purposes of this invention, quaternary phosphonium and sulfonium based salts are defined as within the definition of quaternary ammonium compound.

The raw materials used to make the quaternary ammonium compounds can be derived from natural oils such as tallow, soya, coconut and palm oil. Useful aliphatic groups in the above formula may be derived from other naturally occurring oils including various vegetable oils, such as corn oil, coconut oil, soybean oil, cottonseed oil, castor oil and the like, as well as various animal oils or fats. The aliphatic groups may likewise be petrochemically derived from, for example, alpha olefins. Representative examples of useful branched, saturated radicals included 12-methylstearyl and 12-ethylstearyl.

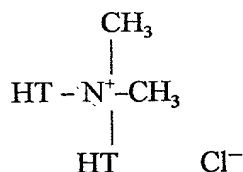
Examples of useful aromatic groups, that is benzyl and substituted benzyl moieties, include benzyl and benzylic-type materials derived from benzyl halides, benzhydryl halides, trityl halides, -halo- -phenylalkanes wherein the alkyl chain has from 1 to 30 carbon atoms, such as 1-halo-1-phenyloctadecane; substituted benzyl moieties, such as those derived from *ortho*-, *meta*- and *para*-chlorobenzyl halides, *para*-methoxybenzyl halides, *ortho*-, *meta*- and *para*-nitrobenzyl halides, and *ortho*-, *meta*- and *para*-alkylbenzyl halides wherein the alkyl chain contains from 1 to 30 carbon atoms; and fused ring benzyl-type moieties, such as those derived from 2-halomethylnaphthalene, 9-halomethylantracene and 9-halomethylphenanthrene, wherein the halo group comprises chloro,

bromo, or any other such group which serves as a leaving group in the nucleophilic attack of the benzyl type moiety such that the nucleophile replaces the leaving group on the benzyl type moiety.

Examples of other aromatic groups include aromatic-type substituents include phenyl and substituted phenyl, N-alkyl and N,N-dialkyl anilines, wherein the alkyl groups contain between 1 and 30 carbon atoms; ortho-, meta- and para-nitrophenyl, ortho-, meta- and para-alkyl phenyl, wherein the alkyl group contains between 1 and 30 carbon atoms, 2-, 3-, and 4-halophenyl wherein the halo group is defined as chloro, bromo, or iodo, and 2-, 3-, and 4-carboxyphenyl and esters thereof, where the alcohol of the ester is derived from an alkyl alcohol, wherein the alkyl group contains between 1 and 30 carbon atoms, aryl such as phenol, or aralkyl such as benzyl alcohols; and fused ring aryl moieties such as naphthalene, anthracene, and phenanthrene.

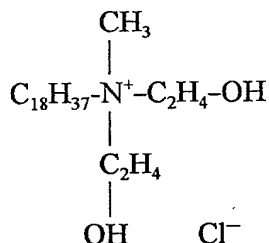
Some examples of preferred quaternary ammonium compounds to make the compositions of this invention are:

Dimethyl dihydrogenated tallow ammonium chloride (2M2HT):

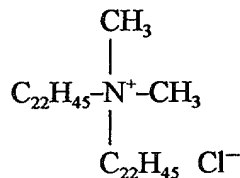


wherein HT = hydrogenated tallow.

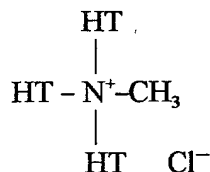
Methyl bis[2-hydroxyethyl] stearyl ammonium chloride (M2HES):



Dimethyl dibehenyl ammonium chloride:



Methyl tris[hydrogenated tallow alkyl] chloride:



A preferred quaternary ammonium compound for purposes of the invention comprises a quaternary ammonium salt that contains at least one, preferably two or three, hydrocarbon chains having from about 8 to about 30 carbon atoms and either no hydrophilic carbon chains or having hydrophilic radicals having a total of about 9 moles of ethylene oxide or less.

It is necessary to have sufficient hydrophobicity in the alkyl chain on the salt to insure that the final product will be non-water dispersible. In general, it is necessary to have at least one of the alkyl chains at least 10 carbon atoms long for this to occur.

The preparation of the quaternary ammonium compounds utilized to make the hybrid organoclay inventive compositions can be carried out by techniques well-known in the art. For example, when preparing a quaternary ammonium salt, one skilled in the art would prepare a dialkyl secondary amine, for example, by the hydrogenation of nitriles (see U.S. Patent No. 2,355,356), and then form the methyl dialkyl tertiary amine by reductive alkylations using formaldehyde as a source of the methyl radical.

Non-anionic organic materials useful for element c) can be selected from a wide variety of non-anionic materials which are either liquids or can be made into a liquid at reaction temperature so that the aforementioned clay materials absorb them. Such absorption is often referred to as intercalation. These materials can be any of a wide range of materials and can have a wide range of molecular weights.

Materials suitable for element (c) of this invention include polyurethanes; polyamides; polyesters; polycarbonates; polyepoxides and polyolefins. Such materials also include polyethers (polymers and copolymers) based on ethylene oxide, butylene oxide, propylene oxide, phenols and bisphenols; polyesters (polymers and copolymers) based on aliphatic and aromatic diols and polyurethanes based on aliphatic and aromatic diisocyanates, polyamides (polymers and copolymers) based on aliphatic and aromatic diamines, and polycarbonates (polymers and copolymers) based on aliphatic or aromatic diols; polycarboimides (polymers and copolymers) based on tetrabasic acids and diamines, vinyl polymers and copolymers based on vinyl monomers, styrene and derivatives of styrene; acrylic polymers and copolymers based on acrylic monomers; copolymers based on styrene, vinyl and acrylic monomers; polyolefin polymers and copolymers based on ethylene, propylene and other alphaolefin monomers; polymers and copolymers based on dienes, isobutylenes and the like; and copolymers based on dienes, styrene, acryl and vinyl monomers. The definition of element c) does not include quaternary ammonium compounds.

Specific preferred examples of useful non-anionic organic materials include THIXATROL VF-10 and THIXATROL VF-20 which are liquid polyester amide copolymers made by RHEOX. Examples of other specific materials are polyvinylpyrrolidone (PVP) or its hydrolysis product, polyvinyl alcohol (PVA), polymethacrylamide, poly(N,N-dimethylacrylamide), poly(N-

isopropylacrylamide), poly(N-acetamidacryl amide), poly(N-acetimidomethacrylamide), polyvinylloxazolidone, and polyvinylmethyl oxazolidone, polyoxypropylene, polyoxyethylene and copolymers thereof.

At least two general methods can be used to make these hybrid organoclays. One is to first
5 disperse the smectite clay in water. The clay is preferably dispersed in water at a concentration of from about 1 to 80%, most preferably from about 2 to 8% by weight. Optionally, the slurry may be centrifuged to remove non-clay impurities which constitute about 10% to 50% of the starting clay composition. The water soluble/dispersible non-anionic organic material is added to the clay/water dispersion and mixed until a clay-organic intercalate is formed. This mixture is then heated and ion exchanged with a quaternary ammonium compound to form the final hybrid organoclay as a coagulate, which is washed with water and isolated by filtration.

The second general method to prepare this invention uses dry clay that is intimately mixed with the non-anionic organic material in a heated device, such as an extruder. The mixture can also have some water present to facilitate intercalation. After the intercalation is complete, the quaternary ammonium compound is added and the final product is produced. This composition can be washed with water and dried.

Both of the methods mentioned above can be modified by either: 1) reversing the order of addition, i.e., react the clay with the quaternary ammonium ion followed by the non-anionic organic material; or 2) adding the quaternary ammonium compound and non-anionic organic material to the
20 clay simultaneously.

The reaction is followed by drying and grinding the organoclay product. Other methods for making this invention can be postulated by those knowledgeable in the art.

5 The preferred amounts and types of clays, organic material and quaternary ammonium compound used to make the compositions of this invention will vary depending upon the type of matrix polymer that each composition is to be mixed into with the goal to achieve substantially complete exfoliation of the clay platelets in the matrix polymer. It is typical that the ratio of component (c) to component (a) clay will be at least 5:100 to 80:100 and more preferably 15:100 to 50:100. The ratio of component (b) to component (a) clay will be determined by the ability to make the final product sufficiently hydrophobic to allow for precipitation and convenient subsequent washing and filtration, as well as good incorporation in the polymer matrix. This will vary depending on the hydrophobicity of the carbon chains attached to the quaternary. Typically, 15 parts of organic cation, more typically 30 to 40 parts per 100 parts of clay are preferred.

A preferred clay/organic chemical composition for purposes of the instant invention comprises the reaction product of:

- (a) a smectite-type clay having a cation exchange capacity of at least 50 milliequivalents per 100 grams of clay; and
- (b) one or more quaternary ammonium compounds in an amount of from about 40% to about 200% of the cation exchange capacity of the smectite-type clay and
- (c) one or more non-anionic organic materials.

The smectite-type clay can be sheared in slurry form prior to reaction with the quaternary ammonium salt, or treated in solid form with a pugmill or similar apparatus.

20 The composition can be used with base materials to make nanocomposites. Such base materials or matrices include almost all plastics, polymers and resins including resins based on formaldehyde and prepolymers thereof and alkyd resins based on dibasic aromatic acids and

anhydrides, glycerol and carboxylic acids, as well as ureas, phenols and melamines. Some of such resins have in the past been used as coatings and have had prior art organoclays dispersed therein.

In addition, polyurethanes of all types produced from isocyanates, polyethers including polyethylene and polypropylene glycols, polyamines, polyamidoamines, polyesters including unsaturated polyesters, plastics based on styrene, vinyl, allyl and acrylic monomers, polyamides, polyolefins and polyimides can be made into nanocomposites by this invention. Polymers also include rubber products including thermoplastic and vulcanizable rubbers.

Preferred matrices are polymeric materials possessing polar functional groups including compounds with hydroxyl, urethane, ester, amide acid, ketone, aldehyde, halide, cyanide and thiol functionality.

Most preferred polymers are plastics which are homopolymers or copolymers of polyesters including linear polyesters, polyamides including nylon and most particularly nylon 6, polyethers, polycarbonates, polyacetal resins and mixtures and blends thereof.

The amount of the clay/chemical compositions of this invention dispersed into the above referenced polymers, resins and plastics to form the inventive nanocomposites varies depending on the particular matrix, its intended use, and the structural strength increase demanded. Preferred amounts are between 1% and 30% by weight of the nanocomposite with a most preferred range being between 3.5% and 12.0%.

For making nanocomposites, the clay/chemical compositions of this invention can be added by any means that can create sufficient shear for mixing. The shear can be provided by any appropriate method such as mechanical, thermal shock, pressure changes or ultrasonics as known in the art. Particularly useful are methods where a flowable polymer is mixed with the hybrid

organoclay by mechanical means such as extruders, roll mills, stirrers, Banbury® type mixers, Brabender® type mixers and continuous mixers.

Nanocomposites that are made by these methods using the compositions of this invention will typically exhibit improved tensile modulus, tensile strength, gas barrier and heat distortion temperature values when sufficient energy is imparted to the blend to create substantially intercalated or exfoliated mixtures.

The clay/organic chemical compositions of this invention can also be used as rheological additives for liquid organic systems, such as paints and coatings, to provide viscosity modification and flow and leveling properties to such systems.

The following examples are given to illustrate the invention, but are not deemed to be limiting thereof. All percentages and ratios given throughout the specification are based upon weight, 100% weight basis, unless otherwise indicated.

Example I

In a baffled three liter reactor with efficient stirring was placed 1350g of a prehydrated aqueous hectorite clay slurry (concentration of clay = 2.8%). The mixture was heated to 70-80° C with stirring. Non-anionic organic materials, as shown below, at a level of 30% based on calculated clay weight were added to the slurry and stirred 15 minutes to effect intercalation. Sufficient alkyl quaternary ammonium compounds in 60 mL of isopropanol were added to react with 100% of the measured cation exchange capacity of the clay and the solution mixed at temperature for an additional 45 minutes.

The initial process used was addition of the non-anionic organic material to the clay slurry quickly as a single shot (Method 1) . It was found that, in some cases, absorption was so rapid as to

cause some clay to not have maximum possible intercalation. Where this was evident by X-Ray diffraction, new hybrid organoclays were prepared using a second method of manufacture (Method 2). This method was addition of the non-anionic organic material slowly to the clay slurry.

The precipitated product was filtered on a large Büchner funnel and redispersed in 1 L of water at 70° C to wash the hybrid clay. The final product was refiltered, dried at 65° C in an oven to give a moisture content below 0.5% and ground to less than 325 mesh. A number of examples are shown in Table 1 showing the d_{001} spacing measured using state of the art X-Ray diffraction measurement equipment.

TABLE 1
Hybrid Organoclays Prepared and Their Properties

Run #	Clay	Non-Anionic Organic Material ⁴	Commercial Name	Quaternary	Method	d ₀₀₁ (Å)	Δd ₀₀₁ (Å) ¹
1	Hectorite	p(vinylpyrrolidone/AA)	ACP-1005 ⁵	M2HES ³	A	22.86	+4.49
2	Hectorite	p(vinylmethylether/MA)	Gantrez AN119 ⁵	M2HES	A	22.86	+4.49
3	Hectorite	p(vinylmethylether/MA)	Gantrez AN179 ⁵	M2HES	A	21.14	+2.77
4	Hectorite	p(vinyl formal)	50,000 MW	M2HES	A	29.47	+11.10
5	Hectorite	p(ethylene oxide)	ca. 100,000 MW	M2HES	A	27.48	+9.11
6	Hectorite	p(vinyl alcohol)	Airvol 523 ⁶	M2HES	A	26.20	+7.83
7	Hectorite	p(ethylene glycol)	8220 MW	M2HES	A	21.97	+3.60
8A	Hectorite	polyamide	THIXATROL VF-10 ⁷	2M2HT	A	36.11	+10.65
8B	Hectorite	polyamide	THIXATROL VF-10 ⁷	2M2HT	B	40.0	+14.5
9	Hectorite	polyurethane	RHEOLATE 204 ⁷	2M2HT	A	33.92	+8.47
10	Hectorite	p(styrene/MA)	SMA 3000 ⁸	2M2HT	A	28.71	+3.29
11	Hectorite	p(dimethylsiloxane)	Antifoam 1400 ⁹	M2HES	A	19.32	+0.95
12	Hectorite	p(dimethylsiloxane)	Antifoam B ⁹	M2HES	A	19.66	+1.29
13	Hectorite	polyacrylamide	10,000 MW	2M2HT	A	31.10	+12.73
14	Hectorite	polyester amide	E1075/ADA/AEPD	M2HES	A	40.69	+22.60
15A	Hectorite	polyamide	THIXATROL VF-20 ⁷	M2HES	A	43.88	+25.51
15B	Hectorite	polyamide	THIXATROL VF-20 ⁷	M2HES	B	40.0	+21.6
16	Hectorite	polyamide	Jef2000/E1004/NMG	M2HES	A	36.11	+17.74
17A	Hectorite	polyester	C15/E1004/E1040	M2HES	A	41.45	+23.08
17B	Hectorite	polyester	C15/E1004/E1040	M2HES	B	40.0	+21.6
18	Hectorite	polyamide	EDA/HSA/E1040	M2HES	A	20.01	+1.637
19	Hectorite	polyamide	EDA/E1004/NMG	M2HES	A	34.71	+16.34
20A	Hectorite	polyester amide	C15/E1004/NMG	M2HES	A	38.59	+20.22
20B	Hectorite	polyester amide	C15/E1004/NMG	M2HES	B	40.0	+21.6
21	Hectorite	polyester amide	C15/E1004/NMG	2M2HT	B	40.0	+14.5
22	Bentonite	p(ethylene oxide)	600,000 MW	M2HES	B	24.9	+4.5
23	Bentonite	polyamide	THIXATROL VF-10 ⁷	M2HES	B	38.6	+20.2
24	Bentonite	polyester amide	C15/E1004/NMG	M2HES	B	44.8	+24.4

¹ Difference in d_{001} spacing from control organoclay, i.e. organoclay made solely with a quaternary compound

² 2M2HT = Dimethyldihydrogenated tallow ammonium chloride.

³ M2HES = Methyl bis[(2-hydroxyethyl)]stearyl ammonium chloride.

⁴ Monomers: Empol (Emory) 1075 - dimer diol, Empol 1004 -dimer acid, Empol 1040- trimer acid, ADA-adipic acid, AEPD-aminoethylpropanediol, AA-acrylic acid, MA-maleic anhydride, Jef2000-Jeffamine D2000 (Huntsman)-diamine, NMG-N-methylglucamine, C15- Ethomeen C15 (Akzo) alkylaminopolyetherol, EDA-ethylenediamine, HSA-hydroxystearic acid.

⁵ International Specialty Products (ISP).

⁶ Air Products

⁷ RHEOX commercial product

⁸ ElfAtochem

⁹ Dow Corning

Description of Results:

Table 1 examples show that a variety of clay/organic chemical compositions cause increased d_{001} spacing in the system tested and that the use of a non-anionic organic material plus a quaternary compound caused an increase in spacing over and above that caused by the quaternary alone (Δd_{001} column).

Example 2

Some of the compositions from Example 1 were selected at random and further tested to determine their ability to disperse in a thermoplastic polymer. PETG, a glycol modified polyester from Eastman Chemical, was used. The polyester was melted and worked on a roll mill at 350°F for 2 minutes to form a melt and an amount of the compositions indicated on Table II was added to the polyester. The dispersion results obtained are indicated in Table II.

Table II
Hybrid Organoclay Dispersion in PETG

Sample	Non-Anionic Organic Material	Method ¹	Hybrid Organoclay Loading ²	Dispersion ³
5	p(ethylene oxide)	A	7.79%	Good
7	p(ethylene glycol) 8K MW	A	7.16%	Very Good
8A	THIXATROL VF-10	A	7.90%	Excellent
8B	THIXATROL VF-10	B	7.62%	Excellent
12	p(dimethylsiloxane)	A	7.16%	Good
13	polyacrylamide	A	7.90%	Poor
14	E1075/ADA/AEPD	A	7.16%	Fair
15A	THIXATROL VF-20	A	7.16%	Fair
15B	THIXATROL VF-20	B	7.03%	Very Good
17A	C15/E1004/E1040	A	7.16%	Good
17B	C15/E1004/E1040	B	7.03%	Very Good
18	EDA/HSA/E1040	A	7.16%	Fair
19	EDA/E1004/NMG	A	7.16%	Very Good
20A	C15/E1004/NMG	A	7.16%	Excellent
20B	C15/E1004/NMG	B	7.03%	Excellent
22	p(ethylene oxide) 600,000 MW	B	7.08%	Very Good

¹ Refers to method employed for the preparation of the hybrid organoclay.

² Hybrid organoclay loading as a percentage of polymer weight.

³ Dispersion is evaluated on a 1-5 scale from poor to excellent as measured by visual inspection and SEM/X-Ray microprobe. A rating of poor corresponds to a sample containing large clay segregates with no dispersed material, and excellent corresponds to a sample that contains no segregates and has clay material evenly dispersed throughout the polymer matrix.

Description of Results:

It is clear that a wide variety of hybrid organoclay compositions prepared according to this invention gave varying satisfactory degrees of dispersion by both visual inspection and SEM/X-Ray probe measurements.

Example 3

Several materials were prepared to compare with the hybrid organoclays the dispersibility in PETG resin of 1) traditional organoclays without intercalated polymer, and 2) clays containing intercalated polymer and no quaternary salt. The former materials were prepared as described in U.S. Patent No. 4,105,578, and the latter by the procedure set forth below:

In a baffled three liter reactor with efficient stirring was placed 1350g of a prehydrated aqueous hectorite or bentonite clay slurry (concentration of clay ca. 3.0%). The slurry was heated to 70-80°C with stirring and organic materials as shown below, at a level of 30% based on calculated clay weight, were added to the slurry. The mixture was then mixed at temperature for an additional 45 minutes and poured into a large stainless steel pan. The materials were oven dried at 65°C, followed by mastication, grinding, and sifting to provide a final product less than 325 mesh.

The materials were incorporated into PETG resin as described in Example 2 and their dispersion observed by visual inspection and SEM/X-Ray microprobe analysis. The results are indicated in Table III.

Table III
Comparative Dispersions

Run #	Clay	Non-Anionic Organic Material	Commercial Name	Quaternary	Dispersion ¹
1	Hectorite	---	---	2M2HT	Poor
2	Hectorite	---	---	M2HES	Poor
3	Bentonite	---	---	M2HES	Fair
4	Hectorite	polyester amine	C15/E1004/NMG	---	Poor
5	Hectorite	p(vinyl alcohol)	Airvol 523	---	Poor
6	Bentonite	polyamide	THIXATROL VF-10 ²	---	Poor
7	Bentonite	p(ethylene glycol)	20,000 MW	---	Poor

¹ Dispersion ranked on a 1-5 scale (Poor, Fair, Good, Very Good, Excellent) by visual inspection and SEM/X-Ray microprobe.

² Rheox commercial product

Description of Results:

5 The examples of Table III demonstrate that neither traditional organically modified clays nor non-quaternized clay intercalates dispersed as well in a polymer matrix as the inventive compositions.

Example 4

10 The hybrid organoclay designated sample 21B (Example 1) was tested against a standard organoclay product, BENTONE 38, for efficiency as a rheological additive in coatings. The two materials were incorporated into a standard aromatic gloss alkyd enamel at 1.00% and their Brookfield and Stormer viscosities measured. The results are shown in Table IV.

Table IV
Hybrid Organoclay 21B vs. BENTONE 38¹ in Solvent Based Paint

Material/Incorp. Method	Stormer Visc. (77°F, KU)	Brookfield Visc. (10 rpm, cP)
Blank	74	550
BENTONE 38/Dry Incorporation	88	3040
BENTONE 38/Xylene pregel	90	3400
Sample 21B/Dry Incorporation	84	1760
Sample 21B /Xylene pregel	89	2400

25 ¹ Rheox commercial product.

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	2101	2102	2103	2104	2105	2106	2107	2108	2109	2110	2111	2112	2113	2114	2115	2116	2117	2118	2119	2120	2121	2122	2123	2124	2125	2126	2127	2128	2129	2130	2131	2132	2133	2134	2135	2136	2137	2138	2139	2140	2141	2142	2143	2144	2145	2146	2147	2148	2149	2150	2151	2152	2153	2154	2155	2156	2157	2158	2159	2160	2161	2162	2163	2164	2165	2166	2167	2168	2169	2170	2171	2172	2173	2174	2175	2176	2177	2178	2179	2180	2181	2182	2183	2184	2185	2186	2187	2188	2189	2190	2191	2192	2193	2194	2195	2196	2197	2198	2199	2200	2201	2202	2203	2204	2205	2206	2207	2208	2209	2210	2211	2212	2213	2214	2215	2216	2217	2218	2219	2220	2221	2222	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236	2237	2238	2239	2240	2241	2242	2243	2244	2245	2246	2247	2248	2249	2250	2251	2252	2253	2254	2255	2256	2257	2258	2259	2260	2261	2262	2263	2264	2265	2266	2267	2268	2269	2270	2271	2272	2273	2274	2275	2276	2277	2278	2279	2280	2281	2282	2283	2284	2285	2286	2287	2288	2289	2290	2291	2292	2293	2294	2295	2296	2297	2298	2299	2300	2301	2302	2303	2304	2305	2306	2307	2308	2309	2310	2311	2312	2313	2314	2315	2316	2317	2318	2319	2320	2321	2322	2323	2324	2325	2326	2327	2328	2329	2330	2331	2332	2333	2334	2335	2336	2337	2338	2339	2340	2341	2342	2343	2344	2345	2346	2347	2348	2349	2350	2351	2352	2353	2354	2355	2356	2357	2358	2359	2360	2361	2362	2363	2364	2365	2366	2367	2368	2369	2370	2371	2372	2373	2374	2375	2376	2377	2378	2379	2380	2381	2382	2383	2384	2385	2386	2387	2388	2389	2390	2391	2392	2393	2394	2395	2396	2397	2398	2399	2400	2401	2402	2403	2404	2405	2406	2407	2408	2409	2410	2411	2412	2413	2414	2415	2416	2417	2418	2419	2420	2421	2422	2
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